Silicon-based lithium ion battery anode active materials – an industry perspective

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The introduction of silicon as an anode active material with high volumetric capacity and low charge/discharge potential will enable cell manufacturers to increase the energy density of lithium-ion batteries up to 40% depending on cathode chemistry and cell design [1].

Besides technical challenges resulting from the volume change during (de-)lithiation, several prerequisites like scalability, reproducibility and economic attractiveness of the active material have to be met to allow introduction into a broad range of applications.

Up to now, three major challenges resulting from the extreme volume change of silicon (~300%) during de-/lithiation hamper the use of silicon-based anode active materials. These are: (i) loss of electrical contact by electrochemical milling, (ii) loss of electrical contact by insufficient electrode stability and (iii) loss of capacity by initial and continuous irreversible lithium-ion loss due to SEI effects.

Different approaches to solve these problems are currently under investigation [2,3]. First of all, the use of nano-sized or nano-structured silicon should reduce the mechanical stress leading to the fracture of silicon. Furthermore, an optimized binder and/or a matrix incorporating the active material should allow for compensating the silicon volume change. Finally and most challenging, industrial feasible concepts have to be developed in order to reduce the initial as well as continuous capacity loss by SEI (re-)formation. Material concepts avoiding or minimizing the contact between the nano-silicon as well as electrolytes for a stable SEI on the silicon surface are viable attempts to solve this problem.

In agreement with literature [4] our findings show that nanosized Si particles with a diameter < 200 nm and carbon composites incorporating these particles proved to be stable during cyclization. In contrast to carboxymethyl cellulose, an in-house developed binder [5] enables high cycle stabilities at application-relevant area loadings (~2 mAh/cm^2). By optimized electrolytes the capacity loss can be considerably reduced. Evidently, even after 300 full cycles silicon significantly contributes to the anode capacity. Combinations of advanced Si-based electrodes with an optimized electrolyte enable to reduce the initial capacity loss to a level comparable to graphite. Several hundred cycles with 80% capacity retention depending on the cathode material (e.g. NMC-111, NCA) have been achieved in full cells with industry-relevant area loading and balancing.

Despite significant progress, the investigated material concepts are still under development and need to be fully implemented in order to achieve the performance required for market introduction (at least 500 cycles at 80 % capacity retention).

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